WFIRST's Dark Energy Observations in the Context of Euclid, LSST and DESI

RACHEL BEAN, CORNELL UNIVERSITY

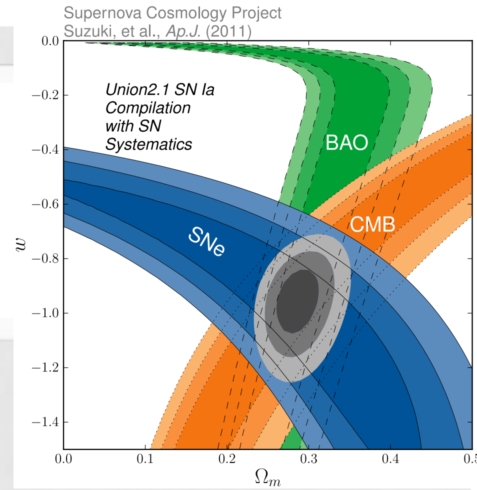
WFIRST (image: NASA)

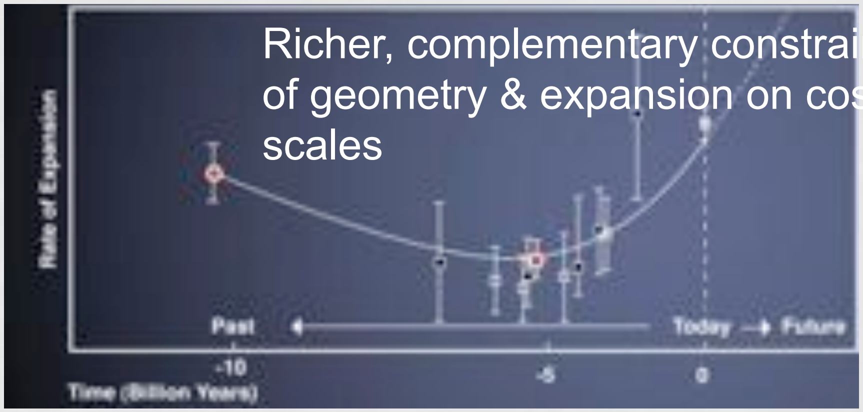
Euclid(image: ESA)

LSST (Image: LSST corporation)

DESI (Image: DESI/ LBL)

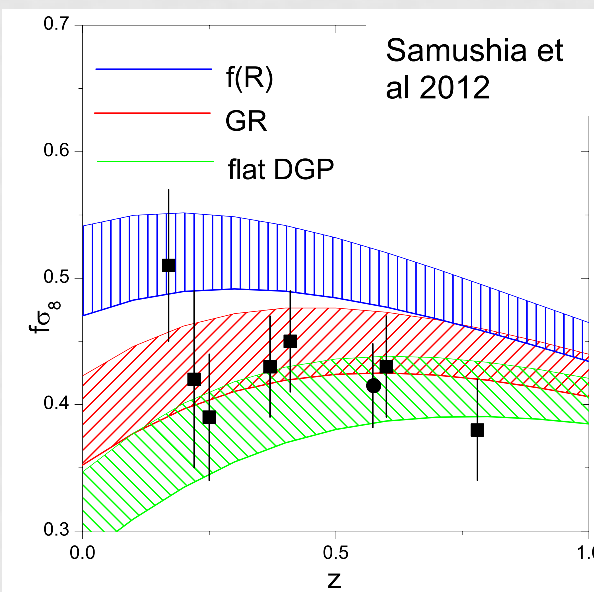
Dark energy science has evolved significantly since its discovery





Richer, complementary constraints of geometry & expansion on cosmic scales

Image: Rostomian and Ross (BOSS/LBNL)

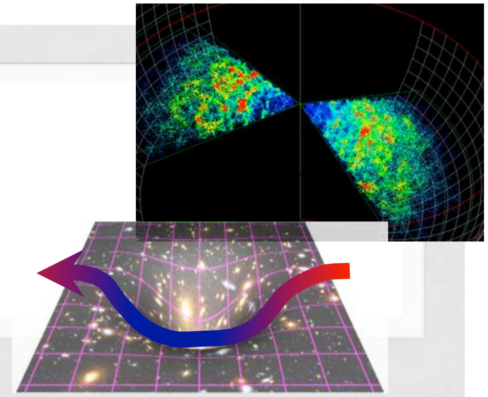


Measurements of the LSS linear growth rate complementary insight to geometry

Category	Theory
Horndeski Theories	Scalar-Tensor theory (incl. Brans-Dicke)
	$f(R)$ gravity
	$f(\mathcal{G})$ theories
	Covariant Galileons
	The Fab Four
	K-inflation and K-essence
	Generalized G-inflation
	Kinetic Gravity Braiding
	Quintessence (incl. universally coupled models)
	Effective dark fluid
Lorentz-Violating theories	Einstein-Aether theory
	Hořava-Lifschitz theory
> 2 new degrees of freedom	DGP (4D effective theory)
	EBI gravity
	TeVeS

Many scalar-based matter and modified gravity theories. “Post-parameterized” formalism bridges theories and survey data.

While the theory can be detailed, the phenomenology can be concise



- Scalar modifications to Einstein equations

Time-time (Newtonian)

$$m_0^2\boxed{\Omega(t)}\left[\frac{2k^2-6k_0}{a^2}\phi^N + 6H(\dot{\phi}^N + H\psi^N)\right]$$
$$= -\delta\rho^N \boxed{-\dot{\rho}_Q\pi^N - 2c(t)(\dot{\pi}^N - \psi^N)}$$
$$\boxed{+m_0^2\dot{\Omega}\left[3\pi^N\left(H^2-\dot{H}+\frac{k_0}{a^2}\right)+3H\left(\dot{\pi}^N-\psi^N\right)+\frac{k^2}{a^2}\pi^N-3\left(\dot{\phi}^N+H\psi^N\right)\right]}$$

Modifications to ΛCDM + GR

Space-space traceless (Newtonian)

$$m_0^2\boxed{\Omega(t)}\frac{k^2}{a^2}\left(\phi^N-\psi^N\right) = \bar{P}_m\Pi + \boxed{m_0^2\dot{\Omega}\frac{k^2}{a^2}\pi^N}$$

Bloomfield et al 2012

- Phenomenology grouped by how they affect relativistic and non-relativistic matter evolution

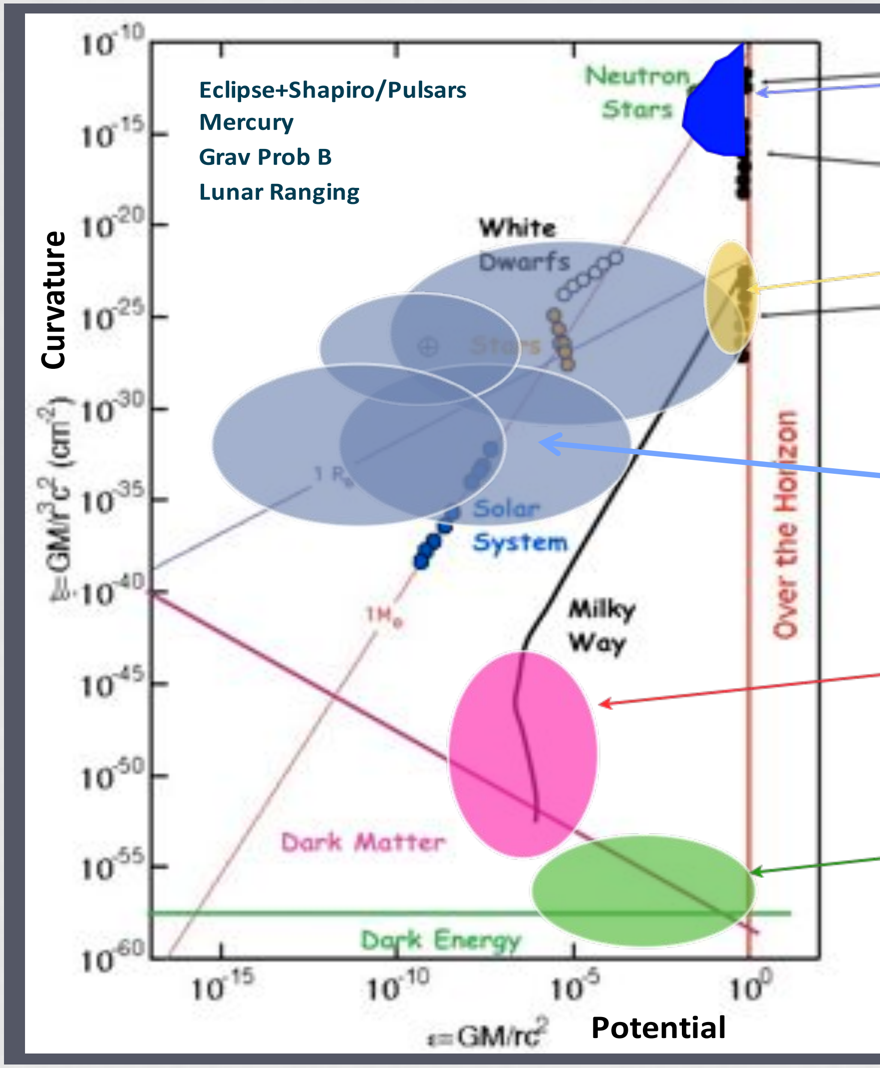
$$k^2\Psi = -4\pi \boxed{G_{\rm matter}} a^2\rho\Delta$$
$$k^2(\Psi+\Phi) = -8\pi \boxed{G_{\rm light}} a^2\rho\Delta\,,$$

Complementarity is the key to testing dark energy

- G_{matter} and G_{light} simpler but still allow powerful
  - new matter: $G_{light} = G_{matter} \neq G$
  - change to GR: $G_{light} \neq G_{matter}$
- Non-relativistic tracers => G_{matter}
  - galaxy positions & motions
  - Growth rate at precise z
  - Bias of tracer (galaxy) an issue
- Relativistic tracers => G_{light}
  - WL & CMB ISW + lensing
  - Direct tracers of potential, but
    - Need to relate lensing and surveyed galaxies
    - Systematics (e.g. photo-z, IAs…)
  - Integrated line of sight
- Cross correlation is vital
  - Reduces uncertainties from bias and initial conditions
  - Get at smoking gun $G_{light} \neq G_{matter}$

Zhang, Liguori, RB, Dodelson PRL 2007

Vital to test of gravity & matter in environ
beyond stellar systems



LIGO

Event Horizon Telescope

Stellar Systems

Galaxy Rotation Curves and Halo Structure

Cosmological Probes

Credit:
Dimitrios Psaltis

WFIRST reflects these advances in measurement & theory

- Don’t presume a strong theoretical prior a-priori
  - Data will be good enough to test beyond w=-1 or w_0-w_a
  - Constrain growth and expansion in a model- independent way

- Search for a diverse array of signatures:
  - Geometry and inhomogeneity constraints across multiple epochs
  - Probe non-linear regimes
    - access many more modes & gravitational screening
  - Multiple tracers sampling distinct gravitational environments
    - galaxy, cluster, CMB and galaxy photons

- Recognizes importance of systematic control in realizing survey potential
  - survey complementarity/cross-correlation
  - Ascribe effects to cosmology rather than uncharacterized systematic.

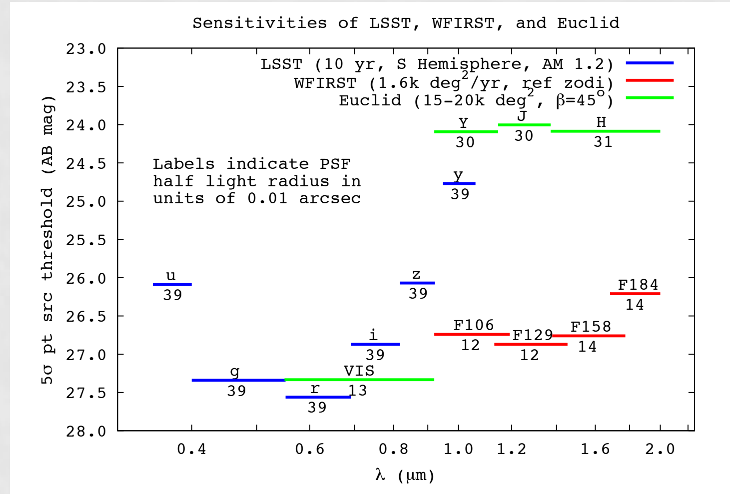
Required breadth, depth & complexity not achievable by a single survey

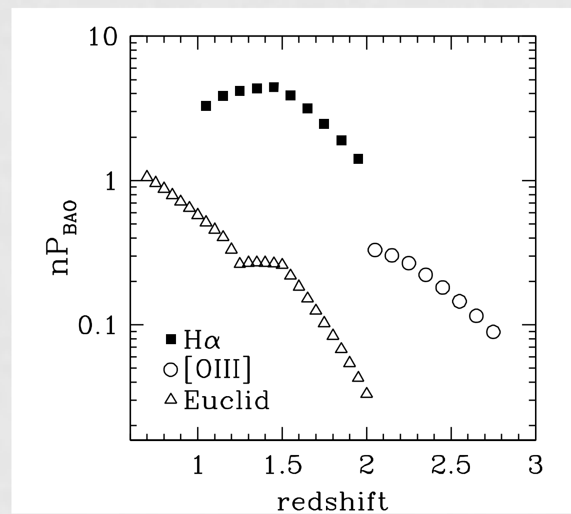
- Trade offs in
  - Techniques (SN1a, BAO,RSD, WL, Clusters)
  - Photometric speed vs spectroscopic precision
  - Angular and spectral resolution
  - Astrophysical tracers (LRGs,ELGs, Lya/QSOs, clusters, CMB)
  - Epochs and scales to study
- Much more than a DETF FoM. Astrophysical & instrumental systematic control mitigation is crucial, but not so easily summarized.
  - Readiness vs technological innovation
  - Survey area vs depth and repeat imaging of the same sky (dithering, cadence and survey area overlap/config.)
- WFIRST, Euclid, LSST, DESI and others will make distinct and highly complementary contributions in these regards

What does WFIRST bring?

In grossly simplified terms:

- All 4 probes (SN/BAO/RSD/WL). Unique SN1a capability with IFU for characterization
- Unique imaging with detailed multi-band, higher resolution lensing and DM mapping than possible from ground or with smaller telescope
- A higher density of spectroscopically selected galaxies for BAO/RSD 1<z<3
- Designed with complementarity to strengths of DESI, LSST, Euclid and others in mind
- Attention to systematics' control as a prime priority (e.g. WL shape measurement, SN1a characterization)





Spergel, Gehrels et al (WFIRST-AFTA SDT) 2013

Many surveys will make key contributions that I've not had time to discuss

- Photometric
  - DES, HSC, Next Generation CFHT
- Spectroscopic
  - BOSS, eBOSS, HETDEX, PFS, 4MOST, LAMOST
- Supernovae
  - DES, J-PAS, JWST
- Other wavelengths
  - ACTPol, SPTPol, Planck, Spider, CCAT
  - XMM, eROSITA
  - ALFALFA, SKA

No doubt I have missed some here, apologies if so.

A summary comparison

(based on publicly available data)

	DESI	LSST	Euclid	WFIRST-AFTA
Starts, duration	~2018, 5 yr	~2020, 10 yr	~2020, 7 yr	~2023, 5-6 yr
Area (deg^2)	14,000 (N)	20,000 (S)	15,000 (N + S)	2,000 (S)
FoV (deg^2)	7.9	10	0.54	0.281
Diameter	4 (less 1.8+)	6.7	1.3	2.4
Spec. res. $\Delta\lambda/\lambda$	3-4000 (N_{fib}=5000)		250 (slitless)	550-800 (slitless)
Spec. range	360-980 nm		1.1-2 μm	1.35-1.95 μm
BAO/RSD	20-30m LRGs/[OII] ELGs 0.6 < z < 1.7, 1m QSOs/Lya 1.9<z<4		~50m Hα ELGs Z~0.7-2.1	20m Hα ELGs z = 1–2, 2m [OIII] ELGS z = 2–3
pixel (arcsec)		0.7	0.13	0.12
Imaging/ weak lensing (0<z<2.)		15-40 gal/arcmin^2 5 bands 320-1080 nm	30-35 gal/arcmin^2 1 broad vis. band 550– 900 nm	68 gal/arcmin^2 3 bands 927-2000nm
SN1a		10^4-10^5 SN1a/yr z = 0.–0.7 photometric		2700 SN1a z = 0.1–1.7 IFU spectroscopy